AN INVESTIGATION OF TARGET ENHANCEMENT USING COLORED BACKGROUNDS ON A SIMULATED RADAR DISPLAY

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THESIS

AN INVESTIGATION OF TARGET ENHANCEMENT

USING

COLORED BACKGROUNDS ON A SIMULATED RADAR DISPLAY

by

William James Wallace, Jr.

Thesis Advisor: Gary K. Poock

September 1971

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An Investigation of Target Enhancement using Colored Backgrounds on a Simulated Radar Display

by

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ABSTRACT

This study investigated the hypothesis that sequential changes of background color on a simulated radar display enhances target detectability. Two experiments were conducted wherein target detectability was assessed in terms of the accuracy in which subjects determined the presence of a randomly appearing target symbol imbedded in visual noise. The first experiment tested 30 subjects to determine the relative detectability of targets among display backgrounds of homogeneous color and backgrounds presenting abrupt changes of color. The second experiment tested 24 subjects to determine if the speed and/or sequence of background color change affected target detectability. Results of the study showed that homogeneous green or blue backgrounds significantly enhanced target detectability when compared to the sequentially changing colored background, and that speed and sequence of background color change have little effect. The study also showed colored backgrounds to enhance target detectability when compared to the conventional method of radar display.

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I. INTRODUCTION

A. BACKGROUND

Adequate visibility is a prerequisite for all visual displays. Accordingly, the design of radar equipment raises many problems of visual discrimination. Radar operators are often forced to search for weak signals at near-threshold levels where factors such as size, brightness, and contrast are critical (Baker, 1962, Chapter 1). In practice, radar signals reflected from a distant target are almost always accompanied by "noise," so that when presented on a cathode-ray tube the real targets are partially or completely obscured by a background of random brightness variations.

In recent years, advances in color cathode-ray tube design and phosphor technology have made it possible to add the dimension of color to radar displays (Feldman, 1958; Mikus and VanNoy, 1967; Beintema, et. al., 1958). Primary emphasis in developing color radar has centered about the use of color for visual coding of information on the display (Burdick, et. al., 1965; Crook, et. al., 1967). Coding in this sense implies that some information of interest, usually an aspect of the operational environment, is associated with a color; an example being to use green in identifying a "friendly" target, while using red to identify an "unfriendly" target.

The utility of a color code, used singly or redundantly in tasks such as searching for a target on a complex visual display, has been

demonstrated in numerous investigations (Anderson and Green, 1956; Smith, 1962; Smith and Thomas, 1964; Jones, 1962; Brooks, 1965; and others). However, it must be noted that since radar systems are semi-automatic, the usefulness of color-coding on radar displays is limited. That is, the addition of a color code as a means of enhancing target recognition occurs only after the raw radar return has been preprocessed for initial target identification by a human operator. Thus, the color code merely identifies "known" targets for tracking or tactical decision making purposes, and does not necessarily enhance the visibility of new targets appearing on the display.

Since maintaining radar operator efficiency over long periods of time remains a continuing problem, it is interesting to note that outside of color coding, the published literature reveals few investigations of other methods for using color to enhance the visual stimulus properties of targets on radar displays.

In view of the human radar operator's ability to visually perceive "change" it would appear that "color change" offers a potential means for improving the operator's ability to visually discriminate target from "noise" on a radar display. Geldard (1962) states that of three stimulus properties that "attract attention," --intensity, change, and repetition-- none is more potent than change.

The "attention getting" potential of "target color change" was investigated by French (1967). Using a specially designed cathode-ray tube containing eight commonly used radar and television phosphors

arranged in wedge shaped sectors around the tube face, French tested 52 Navy sonar school students for performance in detecting a moving target imbedded in visual "noise." Two experimental conditions were employed. Under one set of conditions the target appeared at a sector boundary and moved 45 degrees to an adjacent sector boundary, entirely within a given phosphor color. Under the alternate set of conditions, the target appeared at the medial line of a sector and moved to the medial line of an adjacent sector, resulting in an abrupt change of color midway in the target path. Results of the study showed that the no-color-change condition enhanced detectability when compared to the color-change condition. In discussing the results French reasoned that the anticipated "attention getting" potential of the abrupt target color change was not observed due to lack of repetition in the color changes; i.e. "flashing" the presence of the target to the observer.

While French's study did not verify the potential merits of using "color change" to enhance target visibility, a recent study conducted in the Human Engineering Man-Machine Design Laboratory at the Naval Postgraduate School showed that sequential changes of background color during a search task on a simulated radar display significantly affected detection times. Using two sequences of background color change (red-green-blue; blue-green-red) and three speeds of color change (19.74, 23.52, and 28.59 color changes per minute), Brown (1971) observed significantly lower detection times with the blue-green-red sequence, and significant differences in detection times between speeds of color change. Though

Brown's study did not compare the concept of using sequential changes of background color to conventional methods of radar display, his results do offer evidence that the sequential changes of background color affect target visibility.

Therefore, the present study extends the investigation of using color backgrounds on a radar display to exploit the operator's visual color capabilities in order to improve human filtering of raw radar imputs.

B. OBJECTIVE

The precept for this study was an assumption that sequential changes of background color on a radar scope enhance target visibility by inducing apparent "changes" in target stimulus properties through variations in target-background contrast. It was further assumed that an intrinsic relationship exists between target visibility and target detectability on radar displays, e.g., improved target visibility enhances the operator's ability to detect the target. Accordingly, this study measured target detectability in terms of the accuracy with which operators (subjects) were able to locate a moving target imbedded in visual "noise" on a simulated radar PPI display.

The objective of the current study was twofold. The first objective was to provide a comparison of target detectability between: 1) simulated radar displays using homogeneous background color and 2) a display presenting abrupt changes of background color. The second objective was to augment earlier work (Brown, 1971) with an investigation designed to

determine if target detectability is influenced by speed and sequence of background color change on a simulated radar PPI display.

II. METHOD

Two experiments were conducted to investigate the hypothesis that the presence of sequentially changing colored backgrounds on a radar display enhances target detectability.

Both experiments employed a simple monitoring task to elicit performance measures on subjects simulating the actions of a well trained radar operator. The monitoring task consisted of the subject searching a simulated radar PPI display to determine the presence or absence of a randomly appearing target symbol moving within a constantly changing pattern of irrelevant symbols.

The first experiment investigated the relative detectability of targets among various modes of background presentation, including display backgrounds of homogeneous color and one display presenting abrupt changes of background color as the target moved on the display. A secondary objective of the experiment was to assess the learning effect associated with the monitoring task used.

The second experiment investigated the hypothesis that target detectability is influenced by the speed and sequence in which the background colors on a simulated radar PPI display are varied.

A. EXPERIMENT I

1. Experimental Design

The experiment followed a three-factor partially hierarchal design (Winer, 1962, Chapter 5). The design called for random assignment of thirty subjects, in groups of six, to five experimental conditions, with every subject being commonly measured for performance over three successive series of test trials.

The five experimental conditions represented different techniques of presenting colored backgrounds on the simulated PPI display. Four of the conditions presented a homogeneous background color on the display; i.e., dark gray scope (conventional display), red scope, blue scope, and green scope. The fifth condition presented a continual sequence of changing colors on the scope, the sequence following a repeating transition from blue to green to red.

Within each experimental group subjects were observed under three successive series of twenty-four consecutive test trials, for a total of seventy-two trials per subject. Every trial allowed the subject a maximum of ten seconds to decide whether the target symbol was present or absent on the simulated PPI display. Each series of twenty-four test trials included twelve presentations of a target symbol, and twelve blank or "catch" trials in which the target was not presented. As a guard against experimental bias, the blank or "catch" trials were randomly scheduled throughout each series of test trials using a table of uniformly distributed random numbers. Likewise, the appearance of either of two identical

target symbols was randomly scheduled. A different schedule of target presentation was prepared for every series of trials, and each subject was tested under a different set of schedules.

2. Subjects

Thirty male officer students at the Naval Postgraduate School volunteered to serve as subjects for the experiment. All subjects were accepted for participation without regard to prior experience or background. The subjects ranged in age from 23 to 36 years. Those subjects who habitually wore glasses were required to wear them during the experiment. Each subject was checked for ability to discriminate between the colors presented on the display prior to commencing the experiment.

3. Apparatus

The experimental apparatus used was the Radar Simulator located in the Human Engineering Man-Machine Design Laboratory at the Naval Postgraduate School. The apparatus was used in the earlier study by Brown (1971) and consisted of two parts: a simulated PPI display and a display illuminator (Figures 1 and 2).

The simulated PPI display was a rotating metal disk enclosed in a wooden console, covered by a frosted glass sheet. The faceplate disk, simulating a PPI scope, was perforated with forty 3/32 inch holes located in a random manner about the surface presented to the subject. This disk was permanently attached to a rotating turntable on which twenty-four light sources were rigidly mounted. Thus the faceplate disk and the light sources rotated as a unit. Twenty-four of the forty

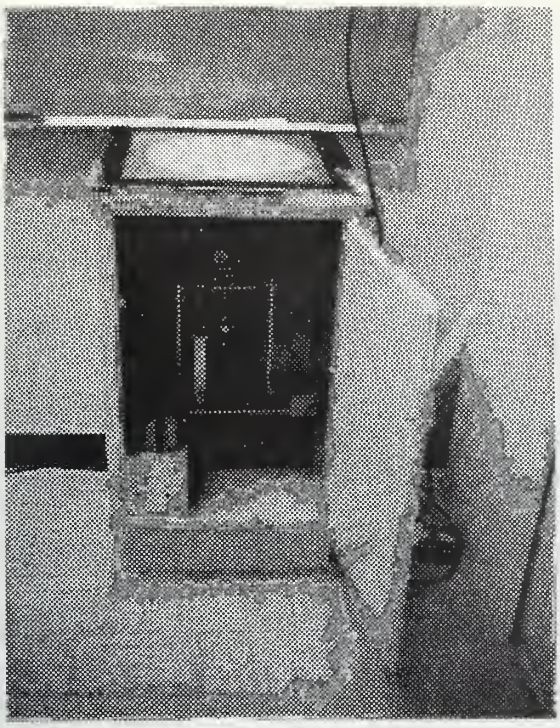

Fig. 1 Simulated PPI Display
(Drive Mechanism Exposed)

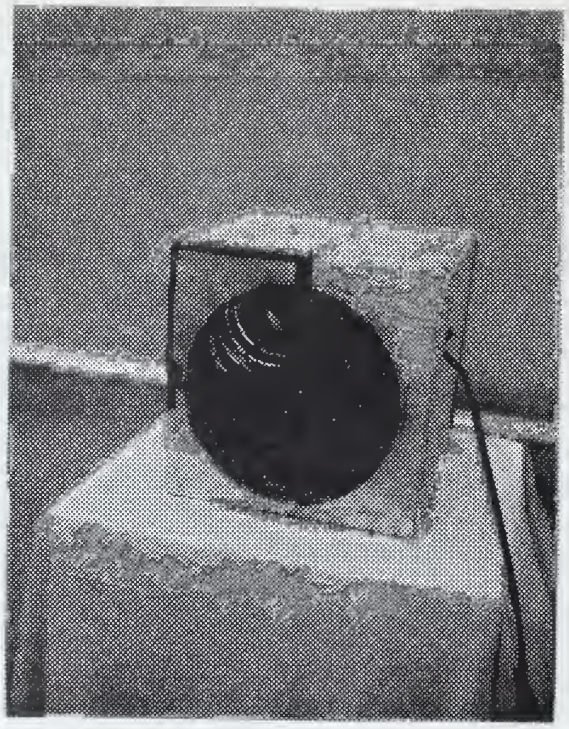

Fig. 2 Display Illuminator

holes projected images onto the frosted glass, and the remaining sixteen holes were permanently masked.

Twenty-two of the light sources projected irrelevant symbols (circles, triangles, and irregular figures), whereas the other two projected identical target symbols (rectangles). All symbols as viewed by the subject were approximately 1/16 inch in length and appeared as white objects moving on a colored background. The irrelevant symbols were controlled electrically by a series of six motor-driven cams, each cam controlling a series circuit of three to five light sources. The cams maintained a pseudo-random pattern of irrelevant symbols on the screen at all times, with from six to twenty-two irrelevant symbols being visible at any one time.

The faceplate disk rotated at approximately 5.17 revolutions per minute and cam cycles for the irrelevant symbols were adjusted so that each circuit was illuminated for 8.6 seconds, and dark for 3.0 seconds. Hence, irrelevant symbols were projected on the screen at an average rate of slightly more than two symbols per second.

The two light sources backing the target symbols were remote controlled from the experimenter's console (see Figure 3) through a four-position Target Select switch, and a micro-switch, designated the Target Present switch. The Target Select switch offered four modes of target presentation. The experimenter could elect to present either, both, or none of the target symbols as he desired, although the option to present both targets simultaneously was not utilized. The Target Present

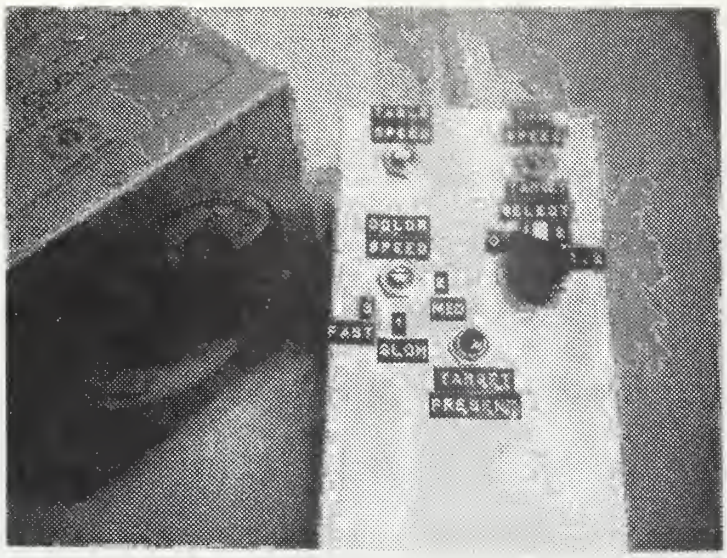

Fig. 3 Remote Console

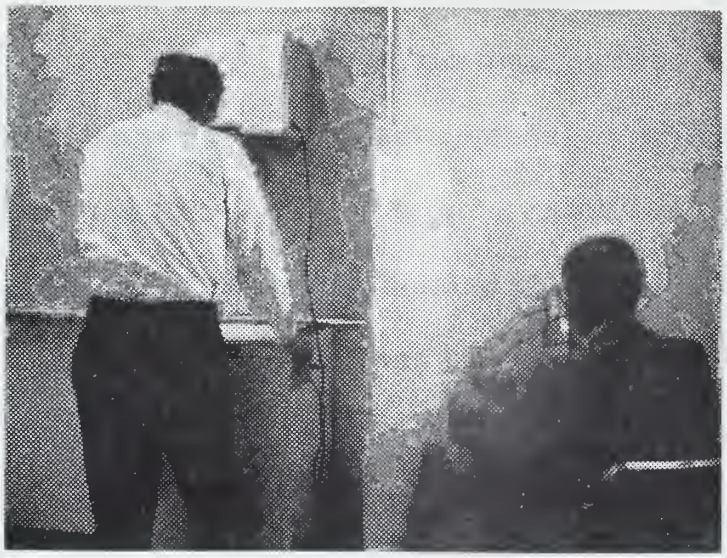

Fig. 4 Experimental Apparatus in Use

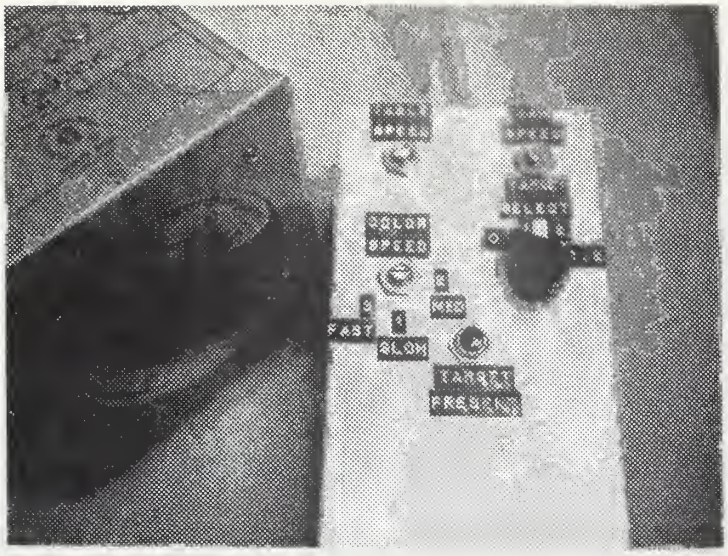

Fig. 3 Remote Console

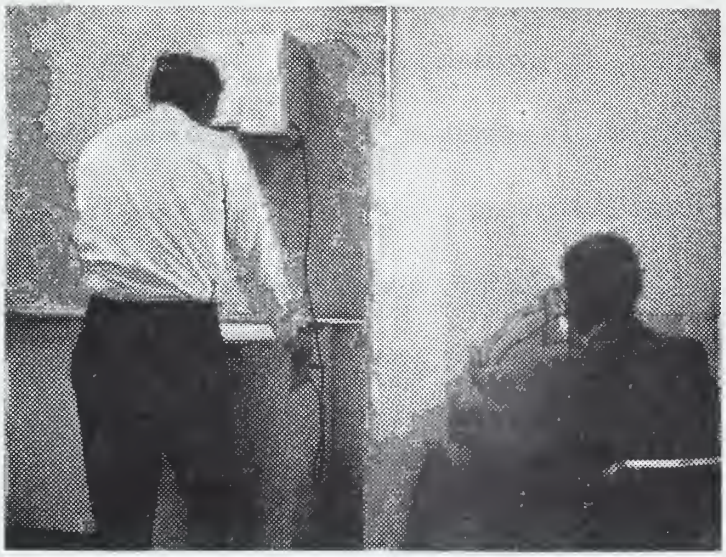

Fig. 4 Experimental Apparatus in Use

switch simultaneously activated the presentation mode selected on the Target Select switch, and a noiseless electric timer.

To illustrate the procedure, if one of the target symbols was to be presented, the experimenter set the Target Select switch to the appropriate target and the Target Present switch was depressed, simultaneously illuminating the appropriate target symbol light source and activating the electric timer. On the other hand, if no target was to be presented, the experimenter set the Target Select switch to present no target, and when the Target Present switch was depressed, only the timer was activated.

When a target symbol was presented, it rotated around the simulated PPI scope until the subject depressed the Target Detect switch located on the right hand side of the display apparatus. Each time the subject depressed this switch, the electric timer stopped. If a target symbol was illuminated when the subject depressed the Target Detect switch, the timer was stopped and the target symbol was extinguished.

The display illuminator consisted of a shielded light source and a rotating color wheel. The unit was positioned above the simulated PPI display at a distance of 26 inches, and located such that the light source projected through the rotating color wheel directly onto the simulated PPI display. The light source for the unit was a standard 150 watt light bulb, and the color wheel was a circular piece of plexiglas mounted on the driveshaft of a VDC motor. The light source was positioned relative to the color wheel such that as the color wheel rotated, only one color was projected onto the display.

The various colors for the experiment were obtained by covering the plexiglas color wheel with sheets of theatrical gel. The homogeneous color conditions were generated by covering the wheel with a single sheet of theatrical gel in the appropriate color, whereas the sequence of colors was obtained by a covering composed of three equal-arc segments of red, green, and blue. To simulate the conventional radar display, or dark gray scope condition, the display illuminator was disconnected from the power source in the simulated PPI unit, and the display appeared as white symbols moving on a dark gray background.

Sequences of color change were controlled by the experimenter through a two-position switch mounted on the side of the display illuminator unit. This switch reversed the direction of rotation of the VDC drive motor in the display illuminator unit.

Speed of color changes in the sequential presentation were controlled by the experimenter through a variable rheostat on the experimenter's remote console.

For all experimental conditions in this experiment the color wheel rotated in a clockwise direction at a speed of 5.9 revolutions per minute. For the experimental conditions requiring homogeneous color on the scope the speed and sequence settings had no effect on the presentation, however for the sequential presentation a continual background color transition from blue to green to red was maintained at a rate of 17.7 color changes per minute.

4. Procedure

On arriving at the laboratory for testing, each subject was given a standard set of printed instructions (see Appendix A) explaining the nature of the task and the response procedure. When the subject had finished reading the printed instructions, the experimenter darkened the laboratory and personally demonstrated usage of the apparatus, insuring that each subject was familiarized with the appearance of the target symbol, irrelevant symbols, and the verbal procedures that would be used in the experiment.

Each subject was encouraged to remove his coat and/or tie, and notified that smoking would be permitted during the experiment.

The experimenter defined the experimental procedure by cautioning every subject that no warning would be given to signify the start of each trial, but that an initial five-second warning would precede the first trial of the experiment.

During the experiment the experimenter was separated from the subject and the display apparatus by a plywood screen (see Figure 4). This provided a further guard against experimental bias in that the subject was not influenced by the actions of the experimenter controlling the display from the remote console, and insuring that since the experimenter could not observe the display, the initial locations of targets presented on the display were randomized.

All subjects were given ten practice trials under test conditions prior to commencing the experiment in order to further familiarize

the subject with the procedures involved. At least five of the practice trials displayed target symbols.

The "method of free response" (Egan, Greenberg, and Schulman, 1961) was utilized to conduct each sequence of test trials. As applied in this experiment, each subject was told only that his objective was to search the simulated PPI display and signify his locating a specified target symbol by depressing the Target Detect button. The subject was not told how many trials were to be conducted in a sequence, nor the temporal interval defining each trial. Since the presentation of targets was randomly ordered in each sequence of trials, the temporal intervals between target presentations were randomly selected. The experimenter made no attempt to influence the subject's decision criterion other than to define the target symbol shape, and specify the "a priori" probability of target presence (i.e. each subject was informed that the target was equally likely to be present or absent during any trial).

As a consequence of using this method of presentation, each subject was tested under a realistic radar monitoring task, where the experimenter was able to insure that the subject would not have prior knowledge of when a target would appear, or of how many targets would be presented during the relatively long observation period.

Following the random schedule of target presentations, the experimenter controlled the presentation of no target for blank trials, and either of the available targets for the balance of the trials. The electric timer was actuated regardless of whether a target was presented

or not, and continued to run until the subject signified location of the target by depressing the Target Detect button, or until time allowed for the trials elapsed, whichever occurred first. If time allowed for a trial elapsed without response from the subject, the experimenter instructed the subject to depress the Target Detect button, thereby stopping the timer. The subject was indirectly rewarded with knowledge of the result of each trial only by noting that the target symbol was extinguished by depressing the Target Detect button. No results were offered by the experimenter.

Each trial was scored for accuracy on the basis of the binary detection theory (Green and Swets, 1966, Chapter 2). Since the subject was forced to decide on each trial whether the target symbol was present or absent on the display, the subject's decision coupled with the state of nature occurring at the time of the decision (i.e. target present or target absent) gave four possible events which could be observed. The following matrix identifies these events.

	Target Present	Target Absent
Decide Target Present	"Hit"	"False Alarm"
Decide Target Absent	"Missed Detection"	"Correct Rejection"

Consequently, those decisions resulting in a "hit" or a "correct rejection" were obviously correct decisions, whereas the decisions resulting in "missed detections" or "false alarms" were just as obviously incorrect.

The experimenter was able to classify the decision made by the subject on each trial in terms of the four events described above. If the subject made no response within the ten seconds allotted for each trial, the experimenter could immediately identify a "missed detection" or a "correct rejection" according to whether a target had been present on the display. On the other hand, if the subject signified target detection prior to ten seconds elapsed time, the experimenter could only distinguish immediately those responses classified as "false alarms." The resulting ambiguity between true "hits" and "missed detections" was resolved by the subject identifying his error if he noted that the symbol selected as target was not extinguished by depressing the Target Detect button.

Accordingly, the percentage of correct response and the numbers of "false alarm" response observed during every series of trials were used as measures of accuracy for each subject.

B. EXPERIMENT II

1. Experimental Design

A randomized block factorial design (Kirk, 1969, Chapter 7) was employed to investigate the hypothesis that target detectability is influenced by the speed and sequence in which background colors are varied on a simulated radar PPI display.

Background colors on the simulated radar scope were sequenced in two ways; either showing a continual repeating transition from red to green to blue, or a like transition from blue to green to red.

The speed of sequential background color change was varied in three ways; slow (14.7 color changes per minute), medium (17.7 color changes per minute), or fast (19.15 color changes per minute).

Blocking on subjects required that each subject be tested under all six possible combinations of sequential background color change, and allowed each subject to serve as his own control.

As a control on experimental bias, a set of randomized permutations of the six experimental conditions was prepared prior to commencing the experiment using a table of uniformly distributed random numbers. Consistent with the requirements of the randomized block design, sequences of experimental conditions from this set were randomly assigned to the subjects participating in the experiment.

Each subject was observed under six series of twenty-four consecutive test trials, for a total of 144 trials per subject. Every series of trials was performed under a different experimental condition, the order of experimental conditions having been predetermined by random assignment. Of the twenty-four trials forming each series, twelve trials presented a target symbol, and twelve trials were blank or "catch" trials. The presentation schedule for blank trials, and the selection of target presentations from the two available target symbols was randomized in a manner identical to that outlined in Experiment I. A different schedule of target presentation was prepared for every series of trials, and each subject was tested under a different set of schedules.

2. Subjects

Twenty-four male officer students at the Naval Postgraduate School, ranging in age from 25 to 39 years, volunteered to participate in the experiment. All subjects were accepted for participation without regard to prior experience or background. Those subjects who habitually wore glasses were required to wear them for the experiment. Each subject was checked for ability to discriminate between the colors presented on the display prior to commencing the experiment. No subject had previously participated in Experiment I.

3. Apparatus

This experiment required only minor modifications to the experimental apparatus outlined in Experiment I.

The color wheel on the display illuminator unit was covered with three equal-arc segments of red, green, and blue theatrical gel in presenting all experimental conditions. Sequences of color presentations were controlled through the two position switch on the display illuminator unit. This switch controlled the direction of rotation of the VDC motor driving the color wheel. Clockwise rotation of the color wheel produced the blue to green to red background color transition, whereas counterclockwise rotation gave the red to green to blue color transition.

A variable rheostat on the experimenter's console governed the speed of the VDC drive motor in the display illuminator unit and controlled the speed at which the colors transitioned on the display. The color wheel rotated at three speeds, 4.9, 5.9, and 6.39 revolutions per minute to

produce the desired color transition speeds of 14.7, 17.7, and 19.15 color changes per minute, respectively.

The balance of the experimental apparatus operated as described for Experiment I.

4. Procedure

The procedural conduct of this experiment varied very little from that outlined in Experiment I. Accordingly, only the differences between the experimental procedures will be reported.

On arriving at the laboratory for testing, every subject was given a set of printed instructions outlining the nature of the task and the response procedures (see Appendix B).

The laboratory was darkened, and after a familiarization demonstration on the apparatus, a series of ten practice trials was given to insure that each subject understood the procedures to be employed in the experiment.

The experimenter signalled the beginning of each series of test trials with a five-second warning, however no further signals preceded the successive trials of a series.

Every subject was allowed a short break of approximately two minutes duration between trial series while the experimenter adjusted the apparatus in setting up the various experimental conditions.

No further differences existed between the procedural conduct of this experiment and that outlined for Experiment I.

III. RESULTS

The data observed in both experiments (see Appendix C) were examined in two categories. The percentages of correct response were analyzed to determine if the various techniques of presenting background color on a simulated PPI display affected the operator's accuracy in detecting the presence of a target. The numbers of false alarm response were analyzed to determine which, if any, experimental technique employed in this study offered potential benefit in reducing the frequency of false alarm response. A five percent level of significance was adopted for all statistical analyses performed.

A. EXPERIMENT I

Graphical representations of the mean percentages of correct response, and mean numbers of false alarm response observed under each experimental condition are depicted in Figures 5 and 6, respectively.

1. Percentage of Correct Response

The percentage of correct response was a proportion assuming a maximum value of one, therefore the arcsin transformation was applied to the observed data in order to achieve the homogeneity of variance assumed in analysis of variance (Kirk, 1969, Chapter 2). A two-way nested analysis of variance in which subjects were nested within experimental groups but common to the three series of test trials was performed on the transformed data. The results of this analysis are shown in Table I.

TABLE I

ANALYSIS OF VARIANCE OF TRANSFORMED PERCENTAGE CORRECT RESPONSE: EXPERIMENT I

Source	df	SS	MS	F	
Between subjects	29	4.6625			
Groups	4	2.7841	.6960	9.27	**
Error (bet.)	25	1.8784	.0751		
Within subjects	60	2.0374			
Trial Series	2	.3861	.1931	7.26	**
Trial Series X Groups	8	.3199	.0400	1.50	N.S.
Error (with.)	50	1.3314	.0266		
Total	89	6.6999			

** $p < .01$

The null statistical hypothesis, e.g., that there were no differences among the five experimental groups with respect to the observed mean percentages of correct response, was rejected. Likewise the null hypothesis that there were no differences in the observed mean percentage of correct response between the three successive series of test trials was rejected. The interaction between experimental groups and trial series was found not to be statistically significant.

A Newman-Keuls test for comparison of differences between all ordered pairs of means (Winer, 1962) was used to assess the significance of differences in the mean percentages of correct response (transformed) between experimental groups (Table II), and between successive series of test trials (Table III).

Although the differences in performance between groups observing different colored backgrounds on the display were found to be highly significant, Table II indicates that only those groups viewing the display with homogeneous green or blue scope backgrounds showed significantly improved percentages of correct response among the conditions under test. Furthermore, it is noted that the difference in performance between groups viewing either green or blue display backgrounds was insignificant.

A comparison of Table III and Figure 5 suggests that a learning effect did exist over the three successive series of test trials, but that the effect was not significant until the third series of trials. Knowledge of the existence of this trend gave the experimenter valuable information for setting up the experimental design used in Experiment II, indicating that the design should provide for additional randomization techniques to counter the learning effect in the monitoring task.

2. False Alarm Response

The assumptions required by parametric analysis of variance were not tenable in the case of the data reflecting the observed numbers of false alarm response. Therefore, a Kruskal-Wallis one-way nonparametric

TABLE II

COMPARISON OF MEAN TRANSFORMED PERCENTAGE OF CORRECT RESPONSE BETWEEN EXPERIMENTAL GROUPS: EXPERIMENT I

Groups (Display Backgrounds)	Dark Gray	Red	Seq.	Blue	Green
Ordered Means	2.0682	2.1613	2.2120	2.4716	2.5136

Differences between pairs:

	Dark Gray	Red	Seq.	Blue	Green
Dark Gray	--	0.0931	0.1438	0.4034*	0.4454*
Red	--	--	0.0507	0.3103*	0.3523*
Sequential	--	--	--	0.2596*	0.3016*
Blue	--	--	--	--	0.0420

Standard Error of a Mean (SEM) = 0.0646

Degrees of Freedom for (SEM) = 25

	r = 2	r = 3	r = 4	r = 5
$q_{.95\,(r,25)}$	2.91	3.51	3.87	4.14
$(SEM)(q_{.95\,(r,25)})$	0.1880	0.2267	0.2500	0.2674

*p < .05

TABLE III

COMPARISON OF MEAN TRANSFORMED PERCENTAGE OF CORRECT RESPONSE BETWEEN SUCCESSIVE SERIES OF TEST TRIALS: EXPERIMENT I

Trial Series	$\bar{I}$	II	III
Ordered Means	2.2171	2.2653	2.3737

Differences between Pairs:

	I	II	III
I	--	0.0482	0.1566*
II	--	--	0.1084*

Standard Error of a Mean (SEM) = 0.0298

Degrees of Freedom for (SEM) = 50

	r = 2	r = 3
$q_{.95(r,50)}$	2.85	3.42
$(SEM)(q_{.95(r,50)})$	0.0848	0.1019

*p < .05

analysis of variance by ranks (Siegel, 1956) was used to test the null hypothesis that sample observations of total numbers of false alarm response, by subject, within each experimental condition, came from the same population. For the parameters defined by this experiment, i.e., five experimental groups and a total of thirty independent observations, the test statistic (H) for the Kruskal-Wallis test is approximately distributed as chi-square with four degrees of freedom. The results of the test ($H = 14.72$) rejected the null hypothesis at the adopted level of significance with $p < .01$.

A nonparametric analog of Dunnett's test, developed by Steel (1959) to compare each of "K" treatments with a control, was used to determine if any of the groups viewing colored display backgrounds made fewer false alarm responses than the group viewing the simulated conventional PPI display (dark gray background). The results of this test showed that all groups viewing colored display backgrounds, regardless of color or technique, made significantly fewer false alarm responses ($p < .05$) than the group viewing the simulated conventional display.

B. EXPERIMENT II

Figures 7 and 8 portray graphically the mean percentage of correct response and the mean numbers of false alarm response observed under each experimental condition.

1. Percentage of Correct Response

As in the analysis for Experiment I, the percentages of correct response were arcsin transformed to satisfy the assumptions of analysis of variance.

A three-way mixed model analysis of variance was used to test the null hypothesis that neither sequence, speed, nor the interaction of sequence and speed of background color change on a simulated PPI display affects percentage of correct response in a monitoring task. The mixed model assumed that subjects were random factors, whereas both speed and sequence of background color change were fixed factors. As shown in Table IV the null hypothesis was accepted in all tests. Thus, it was concluded that for the conditions tested in this experiment the percentages of correct response in a monitoring task are not significantly affected by speed, sequence, or the interaction of speed and sequence of background color change on a simulated PPI display.

2. False Alarm Response

A Friedman two-way analysis of variance by ranks (Siegel, 1956) was used to test the null hypothesis that the observed numbers of false alarm response under each crossed experimental condition came from the same population. For the parameters defined by this experiment, i.e., twenty-four subjects and six crossed experimental conditions, the test statistic (χ_r^2) for the Friedman test is approximately distributed as chi-square with five degrees of freedom. From the results of the test ($\chi_r^2 = 1.83$), there was no indication that the frequency of false alarm

TABLE IV

ANALYSIS OF VARIANCE OF TRANSFORMED PERCENTAGE

CORRECT RESPONSE: EXPERIMENT II

Source	df	- SS	MS	F	
Subjects (Subj)	23	6.7388	0.2930		
Treatments	5	0.1636			
Sequences (Seq)	1	0.0278	0.0278	0.38	n.s.
Speeds (Spd)	2	0.0254	0.0127	0.31	n.s.
Spd X Seq	2	0.1104	0.0052	1.23	n.s.
Residual	115	5.6382			
Subj X Seq	23	1.6619	0.0723		
Subj X Spd	46	1.9114	0.0416		
Subj X Spd X Seq	46	2.0649	0.0449		
Total	143	12.5405			

n.s. - not significant

response depends on the interactive effects of speed and sequence of background color change. Furthermore, the results portrayed by Figure 8 do not in any way suggest that either speed or sequence of background color change contributed markedly toward reducing the average false alarm rate.

IV. CONCLUSIONS

The results obtained under the experimental conditions employed in this study indicate that target detectability may be enhanced when the target is viewed against certain homogeneous colored backgrounds, but that abrupt changes of background color do not necessarily enhance detectability of the target.

From the analysis of the data observed in Experiment I it would appear that although a learning effect was present over the series of test trials in the monitoring task, there were significant differences in performance between groups of subjects viewing the display under different background color conditions. Of particular interest in this respect is the fact that all methods of using colored backgrounds showed some improvement, both in terms of percent correct response and in reducing the frequency of false alarms, when compared to the conventional method of radar display (dark gray background).

The fact that the improvement in the percentage of correct response was statistically significant only in the groups which viewed the target against homogeneous green or blue backgrounds cannot be explained. Initially it was felt that perhaps individual color preference was an external factor influencing the results, therefore every subject participating in Experiment II was asked to rank order the individual colors used in the sequence (red, blue, and green) in terms of working ease; i.e., subjects

were asked to identify the colors which in their opinions aided their ability to detect the target. A Kendall's coefficient of concordance (Siegel, 1956) based on the twenty-four subjects ranking the three colors from best to worst in terms of working ease was insignificant (W = .099). This indicated that there was no common basis for the rankings, although it must be noted that 41.8 percent of the sample felt that the green background best aided target detectability, with the balance being equally divided in preference for the red or blue background.

In view of the fact that there appears to be no consistent color preference pattern among the population of subjects from which the samples for both experiments in this study were drawn, the author concludes that individual color preference does not adequately explain the apparent enhancement of target detectability in the presence of the green and blue display backgrounds.

It may also be stated for the conditions employed in Experiment II that target detectability is independent of the speed and sequence of color change on a display using sequential changes of background color.

While the results of this study do not support the assumption that sequential changes of background color on a radar display would enhance target detectability by inducing target stimulus "changes," it is suspected that at least two factors may have contributed to the failure to observe the anticipated improvement in operator performance.

First, it is thought that the tri-color sequence used in this study may have actually reduced the anticipated target stimulus "change" by

including a color (red) that apparently suppresses target detectability. For this reason, it is recommended that attention be given to a comparison of target detectability in the presence of bi-color sequential changes using the three possible combinations of the colors employed in this study.

There is also reason to suspect that the frequency of background color change in this study was not sufficiently high enough to induce the anticipated target stimulus "change." Therefore, it is recommended that the speed effect be further investigated by employing higher frequencies of color change.

Finally, it is noted that by reducing the "a priori" probability of target presence and by extending the length of the watch period in the monitoring task employed in this study, future investigation might be directed toward the usage of colored backgrounds on radar displays as a potential means for reducing the radar operator vigilance performance decrement (Davies and Tune, 1969).

In summary, the results of this study have indicated that the usage of colored backgrounds on a simulated radar display does offer potential for enhancing target detectability, and that further study of the concept may be profitable in terms of improving radar operator performance.

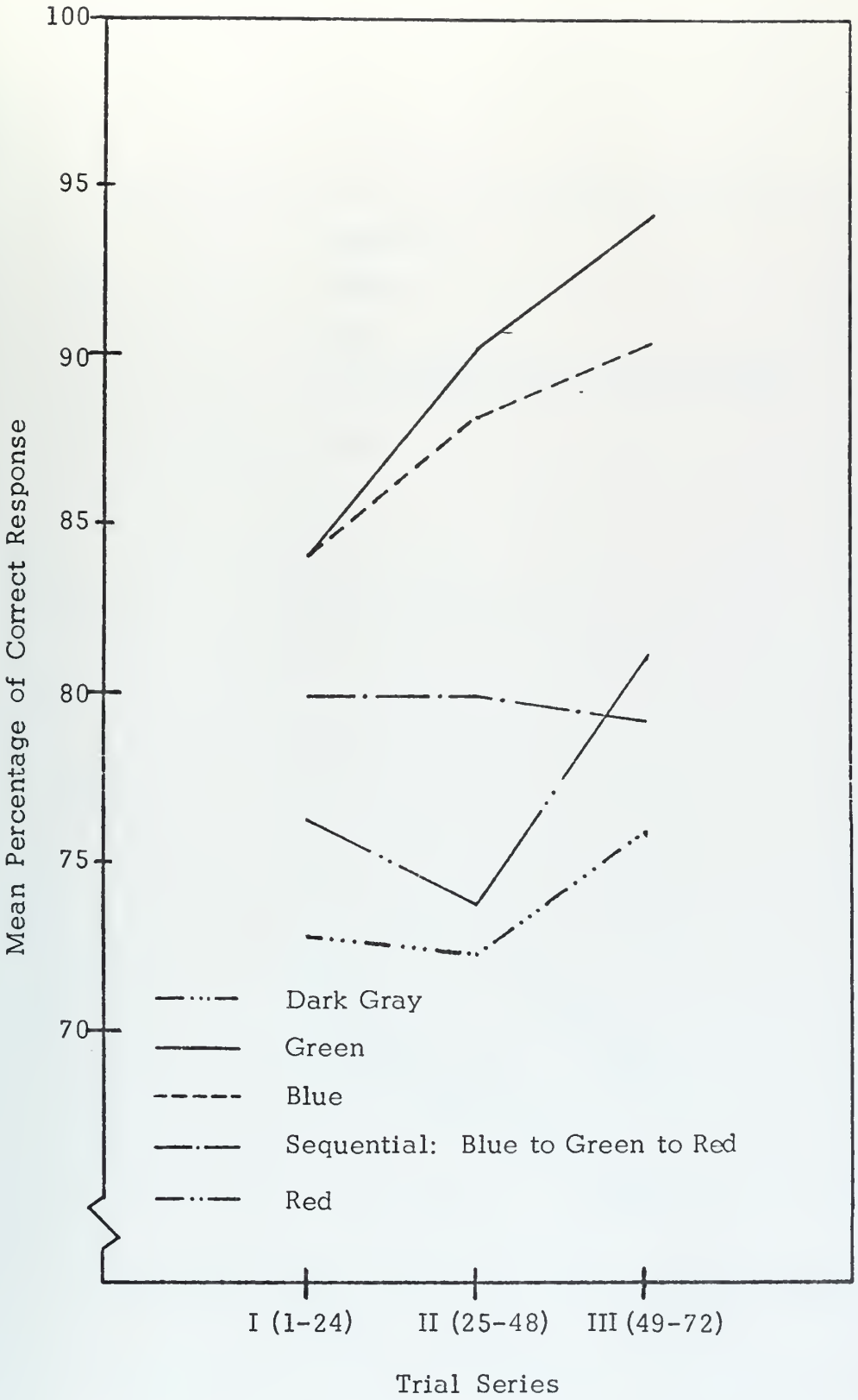

Figure 5 Mean Percentage of Correct Response: Experiment I

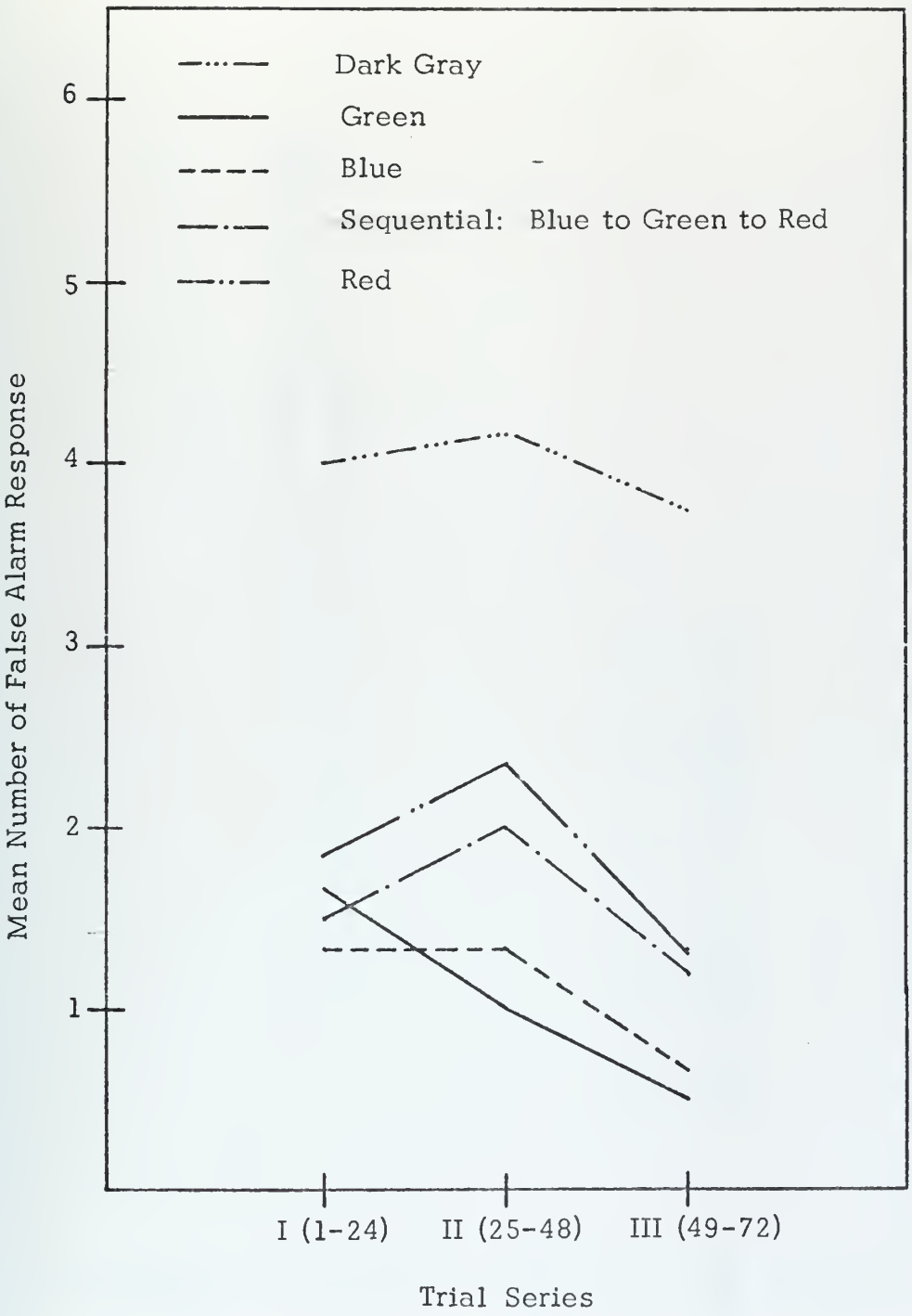

Figure 6 Mean False Alarm Response
Experiment I

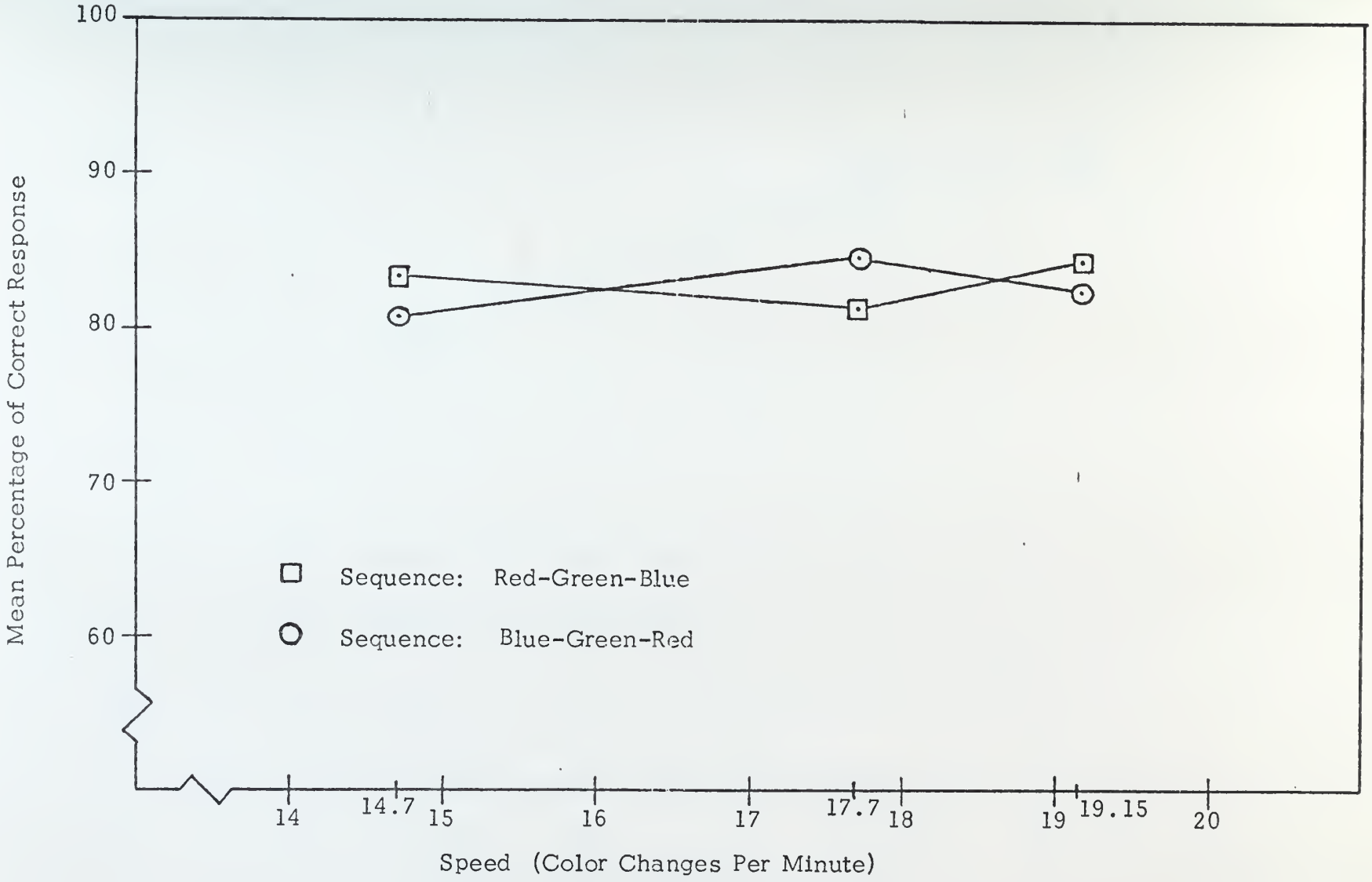

Figure 7 Mean Percentage of Correct Response: Experiment II

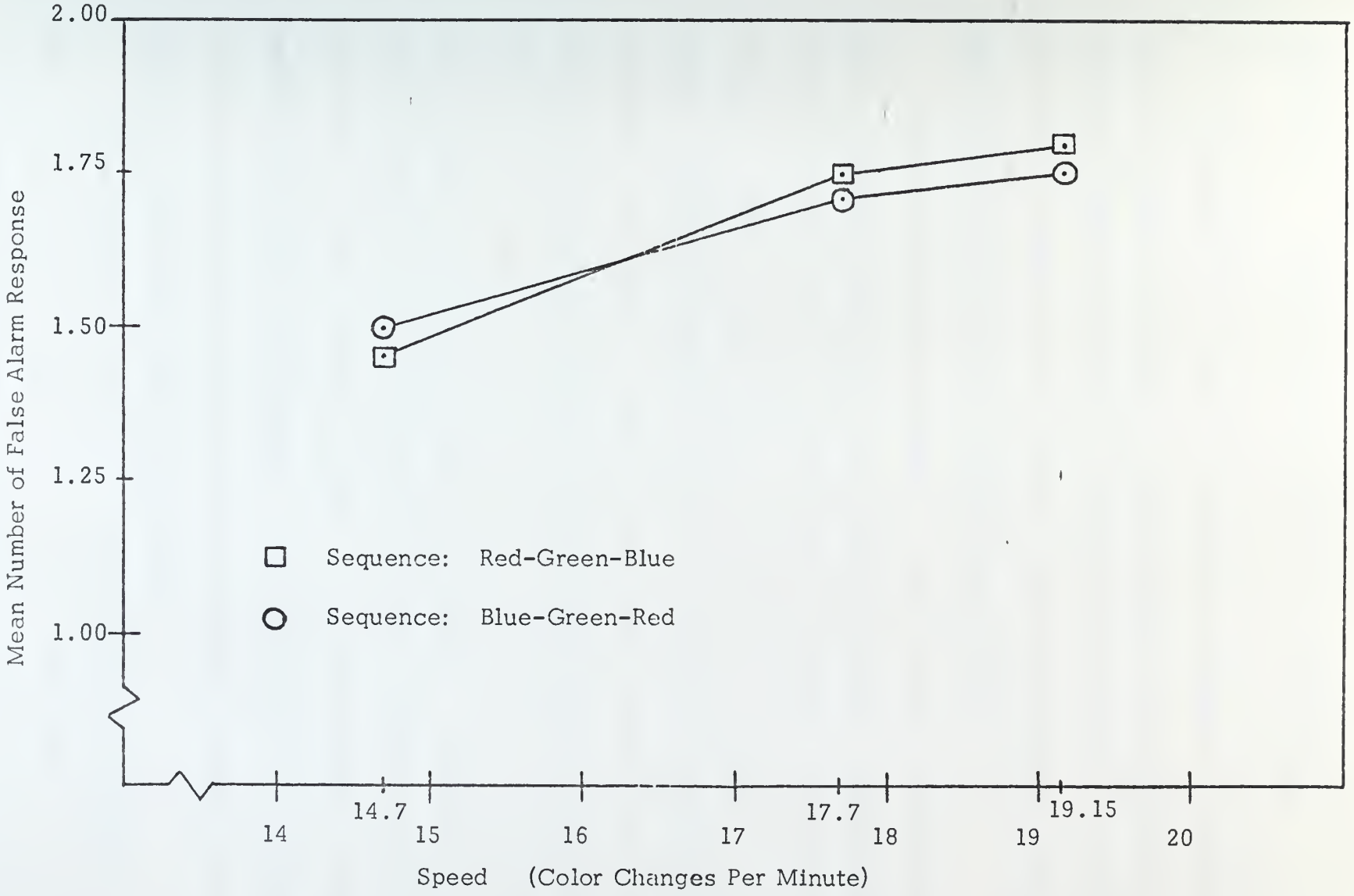

Figure 8 Mean False Alarm Response: Experiment II

APPENDIX A INSTRUCTIONS TO SUBJECTS, EXPERIMENT I

The experiment in which you are about to participate is designed to assess the relative detectability of targets among various techniques of presenting colored backgrounds on a simulated radar display. Your function will be that of simulating a well trained operator searching for a designated target symbol in the presence of simulated radar clutter.

Note the experimental apparatus you will be using. As you can see, there are numerous dark spots moving behind the screen. Throughout the experiment lights will go on and off behind some of these spots projecting a figure ... either circular, triangular, irregular, or rectangular ... on the screen. (A short demonstration was given, and each type of symbol was identified for the subject.) During the experiment you are to stand directly in front of the apparatus looking down at the screen with your right hand on the right side of the top, one finger resting on this button. (The subject was positioned and shown the Target Detect Button.) The target symbol you are to detect is the rectangular-shaped symbol. Depress the button every time you detect the target symbol. If you have correctly identified the target, the symbol will disappear. On the other hand, if you depress the button and the symbol which you have identified as the target does not disappear, please signal me by calling "error."

The experiment will consist of a relatively long watch interval, during which you will be observed on a number of timed trials. In each trial the target is equally likely to be present or absent. The initial trial

of the watch will be preceded by a five-second warning, however the beginning of each successive trial will not be signalled, therefore you must keep your scan of the screen going at all times. The end of each trial will occur when you identify the target and depress the button, or when I call "detect." When you hear me call "detect," please depress the button.

Are there any questions? If not, we will run through a series of practice trials to familiarize you with the procedure.

APPENDIX B INSTRUCTIONS TO SUBJECTS, EXPERIMENT II

The experiment in which you are about to participate is designed to assess whether target detection accuracy is influenced by sequential changes of background color on a simulated radar screen. Your function will be that of simulating a well trained operator searching for a designated target symbol in the presence of simulated radar clutter.

Note the experimental apparatus you will be using. As you see, there are numerous dark spots moving behind the screen. Throughout the experiment lights will go on and off behind some of these spots projecting a figure ... either circular, triangular, irregular, or rectangular ... on the screen. (A short demonstration was given, and each type of symbol was identified for the subject.) During the experiment you are to stand directly in front of the apparatus looking down at the screen with your right hand on the right side of the top, one finger resting on this button. (The subject was positioned and shown the Target Detect Button.) The target symbol you are to detect is a rectangular-shaped symbol. Depress the button every time you detect the target symbol. If you have correctly identified the target, the symbol will disappear. On the other hand, if you depress the button and the symbol which you have identified as the target does not disappear, please signal me by calling "error."

Under each experimental condition you will be given a number of timed trials, in each of which a target is equally likely to be present or absent. The initial trial for each series will be preceded by a five-second

warning, however the beginning of each successive trial will not be signalled, therefore you must keep your scan of the screen going at all times. The end of each trial will occur when you identify the target and depress the button, or when I call "detect." When you hear me call "detect," please depress the button.

At the end of each series of trials we will take a short break while I adjust the equipment.

Are there any questions? If not, we will run through a series of practice trials to familiarize you with the procedure.

APPENDIX C SUMMARY OF OBSERVED DATA

A. EXPERIMENT I

1. Arcsin Transformed Percentage of Correct Response

Group	Subject	Trial Series I	II	III
RED	1	2.1937	1.9107	2.0944
	2	2.0005	2.0944	2.1937
	3	2.0005	2.1937	2.5560
	4	2.0005	2.0944	1.9107
	5	2.4189	1.8235	2.1937
	6	2.1937	2.3004	2.7303
BLUE	7	2.1937	2.7303	2.7303
	8	2.0944	1.9107	2.3004
	9	2.3004	2.4189	2.4189
	10	2.1937	2.5560	2.1937
	11	2.7303	2.5560	2.9373
	12	2.5560	2.7303	2.9373
GREEN	13	2.1937	2.5560	2.4189
	14	2.1937	2.5560	2.5560
	15	2.1937	2.1937	2.7303
	16	2.3004	2.5560	2.7303
	17	2.5560	2.5560	2.7303
	18	2.5560	2.7303	2.9373
DARK GRAY	19	1.9107	2.0944	2.0944
	20	1.9107	1.9107	2.1937
	21	1.9107	2.0944	2.1937
	22	2.3004	2.0005	2.0944
	23	2.0005	1.8235	2.0005
	24	2.3004	2.3004	2.0944
SEQUENTIAL	25	2.4189	2.1937	2.3004
	26	2.1937	2.1937	2.1937
	27	2.3004	2.1937	2.5560
	28	2.0005	2.1937	2.0005
	29	2.3004	2.1937	2.0944
	30	2.0944	2.3004	2.0944

2. Number of False Alarm Response

Group	Subject	Trial Series I	II	III
RED	1	1	1	2
	2	1	3	2
	3	3	2	0
	4	3	0	2
	5	2	6	2
	6	3	2	0
BLUE	7	2	0	0
	8	2	6	2
	9	1	1	1
	10	1	0	1
	11	0	1	0
	12	2	0	0
GREEN	13	3	1	1
	14	3	1	2
	15	1	2	0
	16	2	1	1
	17	1	1	0
	18	0	0	0
DARK GRAY	19	5	5	2
	20	7	5	3
	21	5	3	3
	22	2	4	3
	23	3	6	5
	24	2	2	5
SEQUENTIAL	25	0	4	0
	26	3	3	4
	27	1	1	0
	28	3	1	2
	29	2	3	1
	30	0	0	0

B. EXPERIMENT II

1. Arcsin Transformed Percentage of Correct Response

Subject	SEQUENCE 1 (RED-GREEN-BLUE) SLOW	SPEED MED.	FAST	SEQUENCE 2 (BLUE-GREEN-RED) SLOW	SPEED MED.	FAST
1	2.4189	2.5560	2.1937	2.5560	2.7303	2.3004
2	2.5560	2.9373	2.3004	2.5560	2.5560	2.7303
3	2.7303	2.5560	2.9373	2.4189	2.9373	2.4189
4	2.3004	2.4189	2.4189	2.0944	2.3004	2.1937
5	2.1937	2.3004	2.1937	2.1937	2.1937	2.1937
6	2.3004	2.0944	2.1937	2.1937	2.9373	2.5560
7	2.1937	2.0005	2.5560	2.0005	2.0944	1.9107
8	2.0005	1.8235	2.0005	1.9107	2.0944	2.3004
9	1.8235	2.1937	2.4189	2.3004	2.1937	2.7303
10	2.7303	2.7303	2.7303	2.7303	2.5560	2.9373
11	2.0944	2.7303	2.1937	2.9373	2.7303	2.7303
12	2.5560	2.3004	2.1937	2.3004	2.4189	2.4189
13	2.5560	2.7303	2.4189	2.4189	2.4189	2.5560
14	2.0944	1.9107	2.3004	1.9107	2.1937	2.1937
15	2.0944	1.9107	2.0944	2.1937	1.9107	2.0944
16	2.1937	2.0944	2.3004	2.0944	2.3004	2.0944
17	2.3004	1.9107	2.0005	2.5560	2.1937	2.3004
18	2.9373	2.1937	2.9373	2.7303	2.4189	2.0005
19	2.7303	2.3004	2.9373	2.4189	2.3004	2.3004
20	1.6543	1.6543	1.8235	2.1937	1.9107	1.9107
21	2.3004	2.1937	2.3004	2.1937	2.5560	2.4189
22	2.7303	2.5560	2.5560	2.5560	2.5560	1.9107
23	2.3004	2.5560	2.5560	2.3004	2.1937	2.0944
24	2.4189	2.4189	2.4189	2.9373	2.4189	2.1937

2. Number of False Alarm Response

Subject	SEQUENCE 1 (RED-GREEN-BLUE)			SEQUENCE 2 (BLUE-GREEN-RED)		
	SLOW	SPEED MED.	FAST	SLOW	SPEED MED.	FAST
1	1	0	2	0	1	3
2	1	0	1	1	2	0
3	0	2	0	1	0	0
4	2	1	1	1	4	1
5	0	0	4	3	3	4
6	2	4	3	2	0	0
7	2	3	0	3	0	2
8	3	4	3	6	2	2
9	6	2	2	2	3	0
10	0	0	0	0	2	0
11	1	0	3	0	1	0
12	0	0	2	1	1	1
13	0	1	1	0	0	0
14	3	2	1	1	2	1
15	2	5	5	3	5	3
16	0	0	0	0	0	0
17	0	1	0	0	0	0
18	0	4	0	1	1	6
19	0	0	0	2	2	1
20	9	8	8	5	7	8
21	1	3	2	3	0	2
22	0	0	1	0	0	3
23	2	0	1	1	3	3
24	0	2	3	0	2	2

3. Background Colors Rank Ordered for Working Ease

Subject	BACKGROUND COLORS		
	RED	BLUE	GREEN
1	1	3	2
2	2	3	1
3	3	2	1
4	3	1	2
5	3	2	1
6	1	3	2
7	3	2	1
8	2	3	1
9	1	3	2
10	1	3	2
11	3	1	2
12	1	2	3
13	3	1	2
14	2	3	1
15	3	2	1
16	3	1	2
17	1	2	3
18	3	2	1
19	1	3	2
20	3	1	2
21	3	2	1
22	3	2	1
23	3	1	2
24	3	1	2

Ranking: 1 - Preferred
2 - Next Preferred
3 - Least Preferred

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3. ABSTRACT

This study investigated the hypothesis that sequential changes of background color on a simulated radar display enhances target detectability. Two experiments were conducted wherein target detectability was assessed in terms of the accuracy in which subjects determined the presence of a randomly appearing target symbol imbedded in visual noise. The first experiment tested 30 subjects to determine the relative detectability of targets among display backgrounds of homogeneous color and backgrounds presenting abrupt changes of color. The second experiment tested 24 subjects to determine if the speed and/or sequence of background color change affected target detectability. Results of the study showed that homogeneous green or blue backgrounds significantly enhanced target detectability when compared to the sequentially changing colored background, and that speed and sequence of background color change have little effect. The study also showed colored backgrounds to enhance target detectability when compared to the conventional method of radar display.

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